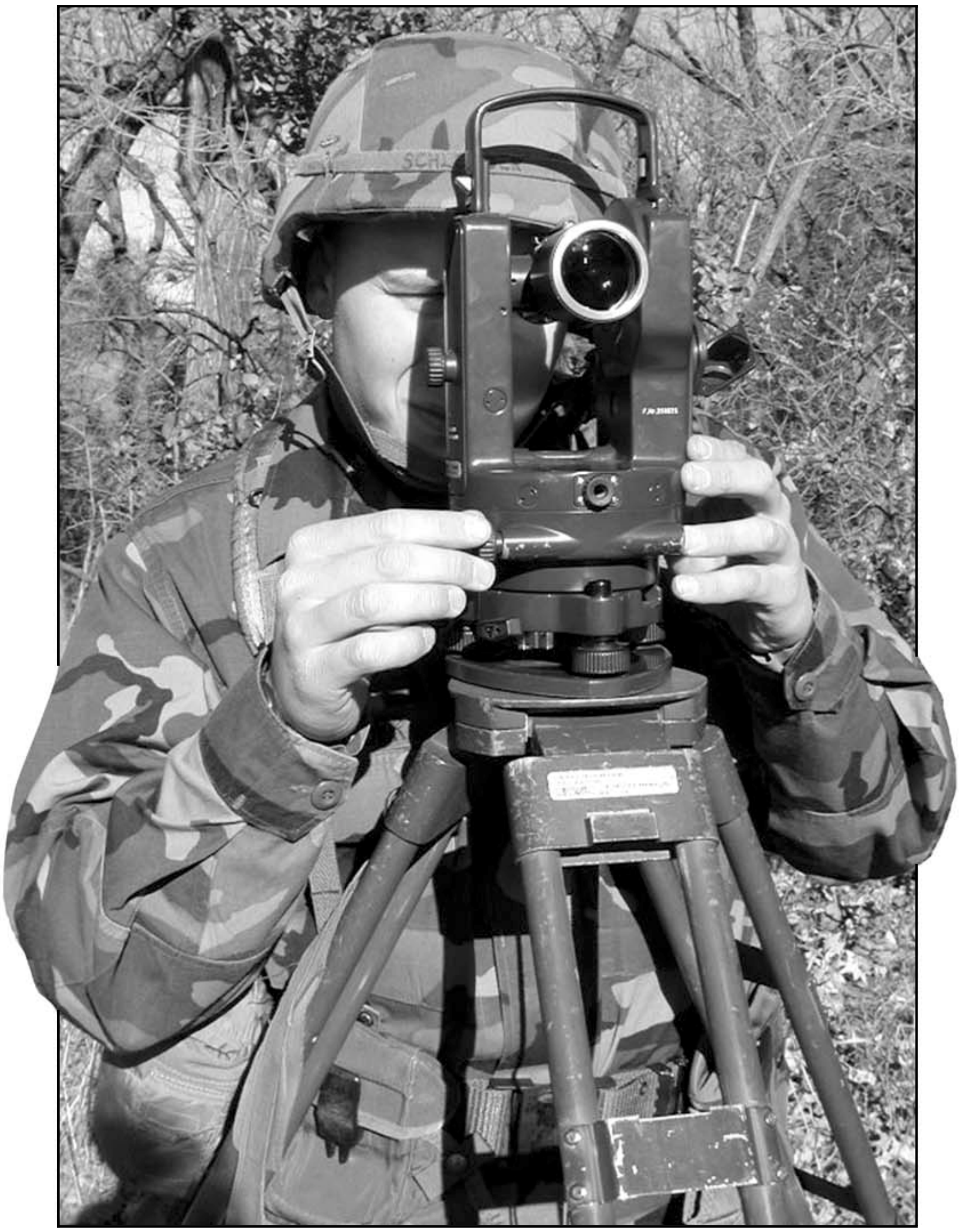
Since the introduction of the global positioning system (GPS) and its integration with inertial navigation systems (INS), many of today's Field Artillery weapons and target acquisition (TA) platforms can quickly and accurately perform self-location and orientation without relying on external survey support. Fielding of systems, such as the gun laying and positioning system (GLPS), modular azimuth positioning system/hybrid (MAPS/H) and the position navigation unit (PNU), have dramatically reduced the number of survey personnel and equipment assets in the Army's FA. US Marine Corps artillery units seemingly will follow suit.

The Bottom Line for Accurate Massed Fires: Common Grid

By Chief Warrant Officer Three Xavier Herrera, USMC



This transformation has redefined the role survey personnel play on the modern battlefield. The primary function of the survey section for many years had been to provide common grid. Under normal operating conditions, platforms with self-location systems no longer require a surveyed firing position to emplace, but they still must maintain a common grid with each other to mass fires and achieve the desired effects on target.

The fire support community must be careful not to dismiss the need to maintain common grid based on platforms' self-location capabilities. With the introduction of digital maps and other digital products into our automated command, control and communication systems, it is imperative that warfighters understand common grid to employ FA and TA systems globally. Without common grid, units can't achieve the desired effects without wasting ammunition and manpower or inflicting damage to the wrong target.

This article discusses common grid and common survey and their targeting issues and provides references and recommendations to ensure accurate, massed fires—time-on-target.

Why is common grid required? *Common Grid is required to permit the massing of fires, delivery of surprise observed fires, delivery of effective unobserved fires, and transmission of target data from one unit to another in order to aggressively neutralize or destroy enemy targets*. (Quoted from the "Field Artillery Position and Navigation Plan" written by the Field Artillery School, Fort Sill, Oklahoma, Page 1. It is online at http://sill-www.army.mil/famag in the "Go-to-War Primer.")

Common grid is the foundation upon which the success of the artillery is built. However, until Operation Desert Storm, most fire supporters never concerned themselves with common grid. During ground combat operations in Desert Storm, rounds missed some targets by up to 750 meters. The culprit was the lack of common grid, specifically due to multiple datums, ellipsoids and grid zones referenced by the maps our joint forces were using.

In once instance in Desert Storm, an aerial observer located an enemy unit and transmitted a request for fire to the supported artillery headquarters for processing. The target coordinate was transmitted to a Navy ship positioned off the coast for prosecution. The ship fired two salvos (rounds) only to have the aerial observer report that the rounds missed the target by 527 meters. Why? They missed because the aerial observer and the artillery headquarters were operating on one datum (Nahrwan Datum) while the ship was operating on another datum (WGS84 Datum). This is known as a "datum shift."

As the result of many similar incidents, the Target Acquisition Department of the Field Artillery School investigated the datum-to-datum capabilities in Field Artillery systems in 1991. Those findings determined that our datum-to-datum capabilities were inadequate, that Field Artillerymen did not understand the subject, that the FA had no standard position navigation (POS/NAV) system requirements and that datums needed to be included as part of *any* position coordinate description.

Today, many of these same common grid issues continue. To gain an appreciation for common grid, Field Artillerymen must first review the five requirements for accurate predicted fire. (See Figure 1.) These five requirements are equally important; however, three of the five *must* be referenced to a common grid to be of value: accurate target location, accurate weapon location and accurate meteorological data.

1. Accurate Target Location and Size
2. Accurate Weapon Location
3. Accurate Computational Methods to Solve the Gunnery Solution
4. Accurate Meteorological Data
5. Accurate Weapon and Ammunition Data

Figure 1: Five Requirements for Accurate Predicted Fire

Common grid allows synchronization of geographic information between all sensors, scouts and forward observers (FOs); weapons locating radars; meteorological measuring systems; delivery systems; and automated command, control and communication systems to mass fires. As our weapons achieve greater ranges, inaccuracies caused by not having a common grid become greater.

What is common grid? Common grid is the sum of several components: the geodetic system, coordinate/grid system, map projection and common or relative survey.

Geodetic System. Within the geodetic system are the datum and ellipsoid. A datum is a mathematical model for the surface of the earth used in mapping a region. There are horizontal datums and vertical datums. All maps do not reference the same datum or ellipsoid (to which the datum is referenced); in fact, there are still more than 1,000 different datums in use around the world today. No single operating system is programmed to operate in all datums; however, some allow the user to define datum entries.

A datum can be local or global. A local datum covers only certain geographic regions. The North American Datum of 1927 (NAD27) is an example of a local datum and is still used in the United States, Canada and Mexico.

Global datums provide worldwide use. Examples include the World Geodetic System of 1972 (WGS72) and the newest, World Geodetic System of 1984 (WGS84).

The National Imagery and Mapping Agency (NIMA), Fort Belvoir, Virginia, considers the WGS84 the preferred datum, which is the datum most of us are familiar with today. NIMA predicts it will take up to 10 years to completely reference the world to the WGS84 Datum, but NIMA will only produce new topographic land maps (TLM) in the 1:100,000 scale.

Many of the existing 1:50,000 scale TLMs could remain referenced to one of several local datums still in use around the world. In some parts of the world, the accuracy error caused by using two different datums can be as much as 750 meters.

When combining the use of TLMs, digital maps or self-location systems, it is *critical* we know what datum we are operating on. Vertical datums are used as references for elevation; the most common is mean sea level (MSL).

The ellipsoid is basically a mathematical model for the size of the earth and is described as an oblate sphere: a sphere that is flattened at the poles. The ellipsoid was once called a "spheroid," and the term is still found on some of the older maps. There are more than five ellipsoids used around the world with WGS84, again, being preferred.

The introduction of GPS technology in the late 1980s made WGS84 the preferred datum because GPS receivers compute all positions on WGS84 latitude and longitude and then convert them to display what datum and coordinate system the user needs.

Coordinate/Grid System. Another component of common grid is the coordinate/grid system. US forces use different coordinate systems. The Army and Marine Corps use the Universal Transverse Mercator (UTM) Grid and Military Grid Reference System (MGRS), while the US Navy uses latitude and longitude expressed in degrees, minutes and seconds. The Air Force uses latitude and longitude expressed in degrees and decimal degrees.

Imagine having an Air Force pilot checking in on station and requesting Army coordinates in latitude and longitude. Too many Field Artillerymen can't plot latitude and longitude on their maps or don't know enough about their handheld GPS receivers to convert coordinates into latitude and longitude. Today's joint operational environments require the warfighter be familiar with all these coordinate systems and know how to convert between the different formats. (See Figure 2.)

1. In the PLGR, store the coordinate as a "Waypoint."
2. Use the "Set-up" menu to view the coordinate in the format needed.
3. Refer to the PLGR operations and maintenance technical manual, TM 11-5825-291-13, Pages 3-66 through 3-73, for further instructions.

Figure 2: AN/PSN-11 Precision Lightweight GPS Receiver (PLGR) Procedures for Converting One Coordinate/Grid System Format to Another. Conversion must take into account the map projection of a particular area of operations.

Map Projection. A map projection portrays all or part of the round earth on a flat surface. This cannot be done without some distortion; therefore, many different projections are used to produce maps. The most common projection is the Transverse Mercator Projection, the standard for NIMA-produced maps.

Many countries use other map projections unfamiliar to our forces that would necessitate their conversion. Fortunately, datum, ellipsoid, grid system and map projection information is found in the margins of all NIMA-produced TLMs. Digital maps and other digital products reference the WGS84 datum/ellipsoid and can be displayed in MGRS, UTM or Geographic grid coordinates using the joint mapping tool kit (JMTK) built into systems, such as the advanced Field Artillery tactical data

GEOTRANS is the Department of Defense conversion software available at NIMA's web site: http://164.214.2.59:80/GandG/geotrans/geotrans.html. The software includes an easy-to-use Users Guide.

Figure 3: National Imagery and Mapping Agency (NIMA) Geodetic Translator (GEOTRANS) Software. This free software converts datums, ellipsoids, coordinates/grids and map projections easily on a personal or laptop computer.

Survey data must be converted to higher echelon data when the two differ by two mils or more in azimuth, 10 meters or more in radial error or two meters or more in elevation. Procedures for converting to the higher echelon data are in *FM 6-2, Tactics, Techniques and Procedures for Field Artillery Survey,* Pages 14-2 through 14-4, or for Marine users, *MCWP 3-16.7, Marine Artillery Survey Operations,* Pages 1-13 through 1-18.

Figure 4: Criteria and References for Converting to Common Survey Data

system (AFATDS). Figure 3 gives the website for the NIMA geodetic translator (GEOTRANS) free software to convert datums, ellipsoids, coordinates/grids and map projections.

Common Survey. Common survey is the final component of common grid and is primarily provided by our artillery survey sections using the position and azimuth determining system (PADS), conventional means or, in the case of the Marine Corps, differential GPS equipment.

Common survey serves two purposes. First, it provides the basic requirement of accurate weapon location in the form of survey control points (SCPs), orienting stations (OS) and known directions, commonly called the end-of-orienting line (EOL). Second, common survey facilitates common grid requirements by ensuring all fire support and targeting assets are oriented the same with respect to azimuth, position and elevation to a prescribed accuracy.

This function has been the mainstay of our survey sections for more than 15 years. In order for two locations to be considered on common survey, they must be referenced to the same datum, ellipsoid and grid system and must meet the prescribed survey accuracies or be converted to meet them.

The highest echelon survey element is responsible for ensuring subordinate units operate on a common grid and common survey network. Subordinate survey elements must establish their survey networks without waiting for higher survey echelon coordination. These elements convert to common survey by comparing higher and lower survey data and converting the lower echelon data to the higher echelon data. Figure 4 outlines the criteria and references for converting survey data to ensure common survey.

Does GPS provide common survey? GPS and its integration with the inertial navigation system have reduced the need for survey sections to provide primary location and orientation data but have not replaced the need to validate common survey.

Understanding GPS is critical if we are to use it to meet common survey requirements. GPS is a space-based radio navigation system designed to provide continuous accurate position, navigation, velocity and time (PNVT) coverage worldwide to an unlimited number of users in both the civilian and military sectors.

When loaded with crypto keys, the precision lightweight GPS receiver (PLGR) provides acceptable horizontal and vertical position accuracy for cannons, rocket launchers and radar systems but *not* the azimuth accuracies required for any FA platform. The PLGR, or any currently fielded GPS receiver, provides a 10-meter circular error probable (CEP) with a 50 percent confidence rate, but it cannot establish fourth or fifth order SCPs or be used for precise targeting. Unless otherwise stated, a 10-meter CEP is defined as the 50 percent probability that a calculated position of a point is within a circle containing a radius of 10 meters from the true position (see Figure 5).

NATO Standardization Agreement (STANAG) 2934 specifies user requirements for position and navigation (POSNAV) accuracies. Figure 6 shows a condensed version of these requirements. As shown in the figure, horizontal position is expressed in terms of CEP in meters, vertical position in probable error (PE) in meters and direction (azimuth) in PE in mils.

Position/direction accuracies and munitions effectiveness are considered parts of the "error budget" for indirect fire weapons and TA systems. An error

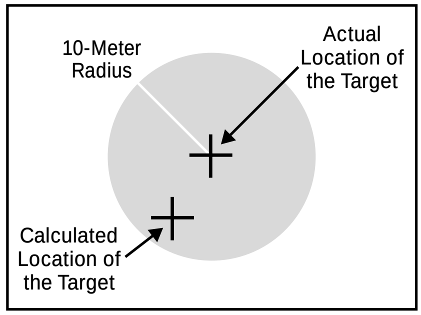


Figure 5: 10-Meter Circular Error Probable (CEP). This CEP has a 50 percent probability that the calculated point will be located in a circle containing a 10-meter radius from the true position of the point.

System	Horizontal Position (Meters) CEP (50%)	Vertical Position (Meters) PE (50%)	Direction (Mils) PE (50%)
105 Towed Howitzer	17.5	10	0.4
155 Towed Howitzer	17.5	10	0.4
155 Self Propelled Howitzer	17.5	10	0.4
MLRS	8	3.6	1
BFIST/Striker	30	20	2
Q-36 Radar	10	10	0.4
Q-37/Q-47 Radar	10	10	0.4
Q-25A/Q-58 Radar	43.7	10	3
MMS	114	10	9

Legend:
BFIST = Bradley Fire Support Team Vehicle
CEP = Circular Error Probable
MLRS = Multiple-Launch Rocket System
MMS = Meteorological Measuring Set
PE = Probable Error

Figure 6: FA Position/Navigational (POS/NAV) Operational Requirements from NATO Standardization Agreement (STANAG) 2934 (A Artillery P-1, "Artillery Procedures," Chapter 11, Annex A, Tables 1-7)

budget encompasses all errors that contribute to the total system accuracy or probable error of the rounds under nonstandard conditions, such as errors incurred by inaccuracies in weapons location, target location, Met data, etc.

Because GPS provides a 10-meter CEP with 50 percent confidence and STANAG 2934 allows for a higher CEP with the same 50 percent confidence rate on many systems, too many Field Artillerymen think the GPS exceeds the standard and they can skip the verification step. That is incorrect—50 percent confidence is not enough to mass fires effectively.

When properly employed, GPS can provide the accuracies to meet common survey requirements, but the user must validate it with an independent means as soon as possible. Sergeant First Class Joseph G. Jacobs, a Fire Support Observer/Controller at the Joint Readiness Training Center (JRTC), Fort Polk, Louisiana, wrote the article "Field Artillery Survey Sections in the New Millennium: New Equipment—Old Requirements" published in the "Combat Training Center (CTC) Quarterly Bulletin" in the First Quarter of FY01 (No. 01-16, July 01) that discusses the use of the GPS and GLPS. He states, "All too often at the JRTC, that crucial second check is not taking place." In other words, commanders often are assuming incorrectly that all positional data produced by GPS-aided systems are correct and accurate.

In combat operations, an independent verification of position and (or) azimuth may not be practical, but in built-up areas where the effects of our fires must be closely maintained, it may be critical. The most important reason to validate any GPS-aided system is due to GPS' vulnerabilities.

What are GPS' vulnerabilities? GPS signals are vulnerable to jamming, spoofing and masking interference. Jamming is the interruption of the GPS signals, and spoofing is GPS signals that have been deliberately duplicated with the intent to fool GPS receivers into using the manipulated data. Masking occurs in built-up areas or in heavy tree cover. Satellites also may be affected by either solar flares or meteors that can cause GPS errors or interrupt GPS signals.

Jamming may be produced by hostile means or accidentally by friendly forces or introduced intentionally in the form of selective availability to prevent adversaries from using our GPS service.

There are valid reasons to be concerned. GPS jammers are easy to build or acquire and would be relatively easy to employ against our forces.

The recent introduction of the selective availability anti-spoofing module (SAASM) will make GPS less vulnerable to hostile jamming and spoofing but will not make GPS foolproof. Modernization plans call for a more robust and less vulnerable GPS service, but the system is not projected for fielding for at least a decade.

GPS vulnerabilities result in many unfavorable possibilities to the user: delays in service, positional errors or complete loss of signals.

What if GPS becomes unavailable? If GPS becomes unavailable, all self-location system platforms can continue to meet mission requirements by using SCP or update point data. SCPs and update points are established by survey teams to provide horizontal and vertical reference. In the event of GPS signal loss, the platforms can continue to use their internal INS along with SCP or update point data to fulfill common survey requirements. These points also provide a means to validate self-location system accuracy and conduct a second independent verification of the positioning data.

Establishing these SCP/update points is the primary task of today's survey teams. The article "Artillery Surveyors: Nomads of the Battlefield" by Chief Warrant Officer Three W. Mark Barnes (January-February 2001) provides additional information regarding GPS vulnerabilities and the criticality of units' training to operate without GPS.

How do units avoid common grid and common survey issues? Training to compensate for our vulnerabilities should be part of every exercise—to include operating without GPS. Most leaders would concur that their units lack skills in basic map reading, use of compasses and terrain association. The PLGR was designed as a navigational aid, yet units commonly train with the PLGR and no map.

Gaining a basic understanding of common grid, common survey and GPS vulnerabilities is the first step in preventing common grid issues. Military planners must account for common grid during the intelligence preparation of the battlefield (IPB) to avoid disrupting the targeting process. To avoid problems with common grid, planners at all levels should ask the questions in Figure 7, and units should use the references in Figure 8.

Conclusion. Despite the enhancements of systems using digital maps and GPS technology, the requirements of common grid remain as valid today as ever. The probability that our forces will operate in areas where the components of common grid will differ between maps and weapons, TA and command and control systems remains high.

1. What are the operational datums and ellipsoids used in the region? There will be many different datums and ellipsoids used during joint operations. Depending on the scale, paper maps may be referenced to one datum and digital maps of the same area may be referenced to a different datum.

2. Have the standard operational datum and ellipsoid been established? The highest echelon survey element should recommend which datum and ellipsoid to use and provide the differences between coordinates that users of topographic land maps (TLMs) should apply to their maps when reporting coordinates. Users must pay attention to the operational datum in use.

3. What are the system capabilities in regards to common grid—is there a workaround established, as necessary, and disseminated to the force? No single system or platform is programmed for all datums, ellipsoids, grids or projection systems.

4. Do we have a backup for the global positioning system (GPS)? GPS has vulnerabilities that may not be apparent to the user until it's too late. Users always should use crypto keys. Users also should validate data, whenever possible—at a minimum with a map spot.

5. Has the signal and communications plan integrated GPS signal frequencies to prevent unintentional jamming by friendly forces?

6. Does the survey plan employ its assets proactively enough to establish common survey requirements and backup capabilities?

7. Have we identified where and who can transform coordinates, if needed?

Figure 7: Questions for Planners to Ask to Prevent Common Grid Issues

Resource	Application
TM 11-5825-291-13 AN/PSN-11 Precision Lightweight Global Positioning System Receiver (PLGR)	Covers and supports all software and hardware versions of the PLGR.
PLGR White Paper Dated 4 December 2000	Addresses the use of PLGR in Field Artillery. Paper is online at http://sill-www.army.mil/gunnery/CourseInfo/courses_download_page.htm#infodoc.
FM 6-2 TTP for Field Artillery Survey MCWP 3-16.7 Marine Artillery Survey Operations (USMC)	Manuals that cover Army and Marine survey operations.
NIMA TR8350.2, Third Edition	A National Imagery and Mapping Agency (NIMA) technical report that defines WGS84 and provides deltas and parameters to convert or define local datums and ellipsoids. It is online at http://mac.usgs.gov/mac/nimamaps/dodnima.html.
The Field Artillery Master Position and Navigation Plan	Provides plans for the current and objective POS/NAV systems architecture. It is online at sill-www.army.mil/famag in the "Go-to-War Primer."
NIMA VHS Film "The Danger Zone"	Excellent 23-minute training film that provides fundamental information on datums, ellipsoids, grids and the global positioning system (GPS). NSN: 7643-01-476-1509
Geodetic Translator (GEOTRANS) Software	Free software used to perform conversions. Runs on Windows-based PC or laptop. Available online at NIMA via http://164.214.2.59:80/GandG/geotrans/geotrans.html.
Backup Computer System (BUCS)	Uses the datum-to-datum coordinate transformation (DDCT) program to perform conversions.
Forward Entry Device Meteorological/Survey (FED MSR) Hand-held Terminal Unit (HTU)	Use forward observer software (FOS) to perform conversions and other survey calculations.

Figure 8: Useful References for Training on and Solving Problems with Common Grid

Somewhere out on the horizon, technology will bring a more accurate and reliable GPS service to merge with systems operating in a globally unified datum, ellipsoid, grid/coordinate and projection system, thus eliminating the need to understand the attributes of common grid or common survey. But until that time, Field Artillerymen must understand the fundamentals of common grid to plan for vulnerabilities and limitations and ensure nothing prevents the delivery of accurate, responsive fires—time-on-target.

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Recognition of Combat Vehicles (ROC-V) Training

ROC-V is a Windows-based thermal/sight computer training program developed by the Communications and Electronics Command (CECOM) Night Vision Electronic Sensors Directorate (NVESD). The ROC-V interactive software helps soldiers identify combat vehicles by sight and their thermal signatures. In addition, ROC-V provides practical experience in thermal sensor image controls—soldiers adjust thermal images to find targets and bring out thermal identification cues.

ROC-V software features high-resolution imagery; a large vehicle set, including helicopters; expanded tactical vehicle descriptions; occluded target views; samples of vehicle sounds; and a separate "iron sight" day-view version. The training modules can display US vehicles with or without their combat identification panels (CIPs). In addition, tutorials explain how the CIPs work and what their identification effects are. The interactive software also includes training and testing for the proposed Soldier's Manual Common Task: Identify day-visual vehicles (Skill Level 1).

The Simulation, Training and Instrumentation Command (STRICOM), Redstone Arsenal, Alabama, has configured ROC-V software for institutional US government users to download. For user name and password to access the website, contact Mike Day at mxregistrar@redstone.army.mil. The ROC-V website is https://rocv.army.mil/ROCV/.

Future versions of ROC-V will include low- and high- angle rotary and fixed-wing aviation and tactical unmanned aerial vehicles (UAVs) for identification training, Potential users and sight system developers, such as project managers who want to discuss the development of ROC-V features to support their missions, should contact the author at commercial (850) 882-6700, Extension 7515 or DSN 872-6700, Extension 7515.

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